A PROVEN KNOWLEDGE-BASED APPROACH TO PRIORITIZING PROCESS INFORMATION[a]

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Many space-related processes are highly complex systems subject to sudden, major transients. In any complex process control system, a critical aspect is rapid analysis of the changing process information. During a disturbance, this task can overwhelm humans as well as computers. Humans deal with this by applying heuristics in determining significant information. This paper describes a simple, knowledge-based approach to prioritizing information. The approach models those heuristics that humans would use in similar circumstances.

The approach described in the paper has received two patents and has been implemented in the Alarm Filtering System (AFS) at the Idaho National Engineering Laboratory (INEL). AFS was first developed for application in a nuclear reactor control room. It has since been used in chemical processing applications, where it has had a significant impact on control room environments. The approach uses knowledge-based heuristics to analyze data from process instrumentation and respond to that data according to knowledge encapsulated in objects and rules. While AFS cannot perform the complete diagnosis and control task, it has proven to be extremely effective at filtering and prioritizing information. AFS has been used for over two years as a first level of analysis for human diagnosticians. Given the approach's proven track record in a wide variety of practical applications, it should be useful in both ground- and space-based systems.

INTRODUCTION

The first section of this paper discusses traditional systems and processes where alarms and information overload have been a problem. Examples of current and future space-related systems with similar characteristics are also described. The following sections discuss how the information overload problem has been addressed in the past and what makes the Alarm Filtering System approach both unique and practical. We then provide a detailed description of the approach as well as a discussion of current applications. In the final section, we look at how the approach might be used today and how future diagnostic, management, and control systems might use the technology.

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THE GENERIC PROBLEM OF INFORMATION OVERLOAD

Today's process and system operators are presented with an ever increasing number and complexity of alarms and information displays. While operators can assimilate this information, stress is placed on the operator in doing so. This stress can lead to mistakes. Pertinent information must be presented in a manner that is clear and concise. Unfortunately, new data acquisition and display technologies have exacerbated the problem rather than alleviated it. The tendency has been to instrument (and alarm) virtually every measurable system parameter. The problem is further compounded by funneling all the measurements and alarms into the control environment. The beleaguered operators are left to analyze massive amounts of data.

This information overload scenario is common across the entire spectrum of process operations and control. The many problems inherent to nuclear power plant control rooms are well documented (Banks, 1981, Christie, 1982, Wahlstrom, 1983). The cascading effect of one or two causal events in a reactor plant can activate hundreds of alarms during the initial five seconds of a transient (Felkel, 1984). While research had begun prior to the Three Mile Island (TMI) accident, that event acted as a catalyst for a generation of work in the area of information display and human factors.

Other industries and types of systems suffer from similar problems. Telecommunications networks can be brought to their knees by a single event that propagates throughout the system. The dynamic nature of many chemical processes (oil refineries, off-gas and scrubber systems, toxic chemical disposal facilities, etc.) leaves operators with little time and no margin for error. Other less dynamic processes can generate a steady stream of alarms and information that gradually wear an operator down. Operators may be less alert when a real problem arises.

Space-related systems based on the ground, in vehicles and platforms, and on the lunar surface will be extremely dynamic and complex. The push towards autonomous control will leave fewer human operators to deal with more problems on a larger number of diverse systems and processes. These systems will range from ground-based systems such as launch and communications to space systems such as propulsion, power, environmental, and operational. Indeed, the importance of recognizing and responding to casualties has already been recognized for future missions and operations. In discussing the control of transfer and orbital operations, Ramsthaler states, "the first line of defense against a major failure is adequate knowledge of the situation as it is developing" (Ramsthaler, 1988). In discussing potential problems related to propulsion, Ramsthaler makes the point that "in order to avoid major damage to an engine, action would have to be taken within seconds of the failure for many of the items." These concerns will continue well into the future as the same types of systems are specifically mentioned in proposals for projects that would culminate 50 years from today (West, 1989).

GENERIC APPROACHES TO SOLVING INFORMATION OVERLOAD

One primary goal of data acquisition and information display

is to present the needed information at the appropriate time. An effective way of addressing information overload would be during the design phase of the system or process to be monitored. By properly identifying the required information, system designers could reduce the incoming data to a manageable amount. Unfortunately, one can postulate situations where virtually any specific process information could be useful. As a result, everything is instrumented, and all of that data is brought into the control environment.

Bringing all the data into the control environment ensures the needed information is always available. In fact, it ensures that for a given situation a large amount of extraneous information is also always available. This extraneous information overloads the operators. Measures must be taken to focus operator attention on important information as effectively as possible. Various types and levels of information processing have been used for decades (Baker, 1985). The functional grouping of information and alarms is one rudimentary form. With the advent of computers and microprocessor based displays, static prioritization has become feasible. Static prioritization, which is widely available in industry today, allows facilities to assign a predetermined priority level to an alarm or piece of information. That priority remains constant (or static) no matter what the situation is. Recall the goal of providing the needed information at the appropriate time. Static prioritization is a step in that direction. It does not, however, adequately account for the dynamic nature of processes and systems. When looking at the entire spectrum of process states, a piece of

information probably does not have a single level of importance relative to other information from the process. Often, that relative importance varies from a high level to a level of being extraneous.

The next step in information and alarm prioritization has to take into account the state of the process or system being monitored. The Alarm Filtering System (AFS) is such a step towards providing needed information at the appropriate time.

ALARM FILTERING SYSTEM

As mentioned earlier, considerable effort has been made in developing operator aids for the nuclear power industry. Several tools have been proposed or implemented in such systems as DMA (Diagnosis of Multiple Alarms) (Danchak, 1982), STAR (Felkel, 1984), and DASS (Disturbance Analysis and Surveillance System) (Long, 1980). These systems addressed the dynamic nature of processes by using logic or cause-consequence trees to identify the process state and emphasize information accordingly. These trees are difficult and expensive to build, tend to be inflexible to change, and are not easily maintained over the life of the plant (Baker, 1985).

The Alarm Filtering System (AFS) was originally developed to address the problems caused by onrushes of alarms in nuclear power control rooms. We have since applied the approach to other processes and to other information besides just alarms. We have found the approach to be responsive (in terms of processing information), relatively easy to develop and maintain, and effective in helping to manage the information in the control environment.

AFS determines the importance of alarms and information relative to its knowledge of the current plant state. When process information is provided, AFS assigns a level of importance to it. As the process subsequently changes and other related information becomes available, that level of importance is reevaluated and possibly changed. Thus, the prioritization is dynamic, changing as the process changes. Important information is emphasized while information not pertinent to the current situation is deemphasized and, in some case, eliminated. AFS uses relationships between alarms and information as a basis for determining importance. These relationships and their associated rules are used by AFS to:

- Generate a description of a situation implied by combinations or sequences of information,

- Suppress information that simply confirms or is a direct result of a previously described situation,

- Emphasize information that does not correlate with previous conclusions or information that is expected (due to previous conditions) but is not received within specified time limits. This expected information is typically the result of automatic system response to a process state or operator action.

The approach used in AFS resulted from applying expert system concepts to the problem. We looked at the information processing problem from the operator's view point and modelled the operator's methodology for rapidly analyzing changing information. We recognized that operators use relationships between pieces of in-

formation as a basis for determining relative importance. Five types of relationships were identified during the development and application of AFS. Each type of relationship has a set of possible responses and decisions that can be made. Thus, each type has a set of rules associated with it that model how alarms and information should behave and what levels of importance should be assigned. The five types of relationships are level and direct precursors, required actions, first-out, and blocking conditions. These are discussed in greater detail in the descriptions of the two patents on the approach (Corsberg, 1988, 1989). There is nothing particularly complex about these relationships. It is their practical application to process information management that produces effective results. The level precursor relationship is an excellent example. This relationship typically occurs when the same parameter has two alarm setpoints. Thus, alarm A's setpoint would be at one level (a lower reading), while alarm B's setpoint would be at another (higher) reading. Alarm A should always be activated before B. If both are activated, then B should deactivate prior to A. In terms of prioritization, if both A and B are activated, B should be at a higher level of priority than A. If only A is activated, it should be emphasized at the highest level (unless another related piece of information affects its priority). As mentioned above, these priorities are dynamic. Thus, if both A and B were activated, and B is then deactivated, A's priority would be updated based on the new set of information.

The use of objects and their associated mechanisms has been of particular importance in the successful development of AFS. AFS

uses information about the processes and systems being monitored as well as parameters and other types of information. Each of these entity types is represented by a class that acts as a blueprint for building specific objects. All objects in a class will have the same structure because they were all built from that same blueprint. Each specific object in a class has a different information content based on the entity it represents (rather than on the type of entity).

In addition to providing structure for objects, classes also associate functionality with the objects. This functionality takes the form of programming procedures that are invoked when objects send messages to each other. These procedures are common to all objects in a particular class. The rules concerning behavior and priority levels are encapsulated in these procedures. The ability to associate a procedure with an entire class of objects has greatly increased the modularity of AFS and reduced the total number of rules required. Specific data about each piece of information is contained in the object representing that piece of information. The more general knowledge about responses and actions caused by the relationships is contained in the procedures. This separation of knowledge provides the modularity to make AFS flexible. During the development of an implementation, developers can focus on the process and its parameters rather than on the more generic portions of the approach. Changes can be made with minimal impact on nonrelated portions of the implementation.

AFS APPLICATION AND KNOWLEDGE ACQUISITION

AFS has been installed in nuclear reactor control room simulator and in the control room of a chemical processing facility. Two important issues in the application process are the information displays and the knowledge acquisition process. As the reader may have noted already, this paper has not mentioned information displays. One reason is that AFS is relatively independent of these displays. AFS acts as an in-line processor between the instrumentation and the information displays in the control environment. AFS simply assigns a priority to each piece of information. What is done in response to that priority is entirely up to the specific facility (and, possibly, even a specific operator). AFS has been used in facilities where the associated display is a graphical mimic of the process. The same AFS approach has been used in conjunction with simple scrolling text windows where the AFS-assigned priorities were used to determine what to scroll off the window and what to leave on. This modularity allows AFS to be integrated into any environment that has an open architecture.

When discussing AFS, the most common and immediate question is about how the relationships between the information are determined. The relationships are defined through the process of knowledge engineering, a discipline that has grown out of expert systems and artificial intelligence. We start by clearly defining the information and alarms to be processed. (This turns out to be a difficult task in itself.) We use engineering, training, and operational documentation as a way of becoming familiar with the pro-

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cess and its terminology. We then go through an exhaustive and iterative process of identifying and justifying relationships between information and alarms. This process of extracting the knowledge, putting it to paper, and then refining it had little to do with computers. In fact, the close examination of data acquisition and alarm systems revealed several items and assumptions that were incorrect.

During the design of a facility, engineers will anticipate some of the information problems and will effectively tune them out. However, not everything can be predicted, and there are always extraneous, spurious bursts of information that are generated once a process or system begins operation. All AFS applications have had significant operating experience to draw on. This experiential knowledge has been the foundation of the knowledge bases in these applications. Many potential AFS space applications would not necessarily have this experiential knowledge to draw on. Potential areas to acquire this knowledge from include training facilities and simulators. The fact that AFS can be changed easily would also allow for modification once systems have been deployed. These changes could be effected remotely since AFS is implemented entirely in software.

AFS has proven to be an effective aid to operators. It adds minimal time to transmitting process information to the control environment. Versions implemented in the programming language LISP add between 10 and 20 milliseconds to the total time response. As implementations in more traditional programming languages such as C come online, these times will be further reduced. One application

has been used for nearly three years without a single failure. That application has reduced message traffic by more than 80%.

AFS AND SPACE

AFS is a step towards more effective management of process information. It is not a stand-alone system. AFS applications must be developed and integrated into a total environment of information acquisition, processing, and display. Many potential space-related applications could be developed today. These include ground-based launch, control, and communication systems where information management problems have been identified. In these cases, AFS could be used to directly influence the information being displayed to operations personnel.

Future applications would probably use the AFS approach in a different way. AFS uses experiential knowledge and has no real in-depth understanding of the systems and processes being monitored. As more sophisticated diagnostic and control systems are developed, AFS's role would change from that of providing more effective information to humans. Instead, AFS would act as a front-end to automated software with complicated models and knowledge bases. The knowledge used in AFS is a highly effective way of rapidly identifying a situation and can be envisioned as handling a high percentage of information management problems. To handle more difficult problems, AFS applications would need to be incorporated into a much larger environment of cooperating knowledge-based systems. These other systems would handle the more complex and computationally intensive tasks of diagnosis and control. AFS applications would still provide the needed in-

formation at the appropriate time. Rather than providing that information to humans, AFS would be working with other software systems, improving their quality and effectiveness.

CONCLUSION

This paper has described a knowledge based approach to prioritizing process information. This approach, AFS, has been developed and successfully used in nonspace applications. AFS has proven to be an effective step towards solving many real-time information management problems in control rooms. These same problems exist, or will exist, in the control environments of current and future space-related systems. As such, AFS should be generally applicable to a wide variety of space applications.

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